Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: 0 672 891 A1

(12) EUROPEAN PATENT APPLICATION

(21) Application number: 95103588.0

(51) Int. Cl.6: G01D 5/26, G01D 5/38

(22) Date of filing: 13.03.95

(30) Priority: 14.03.94 JP 70004/94
07.03.95 JP 74620/95

(43) Date of publication of application:
20.09.95 Bulletin 95/38

(84) Designated Contracting States:
DE FR GB IT NL

(71) Applicant: CANON KABUSHIKI KAISHA
30-2, 3-chome, Shimomaruko,
Ohta-ku
Tokyo (JP)

(72) Inventor: Kaneda, Yasushi, c/o Canon Kabushiki Kaisha
30-2, 3-chome, Shimomaruko,
Ohta-ku
Tokyo 146 (JP)
Inventor: Ishizuka, Koh, c/o Canon Kabushiki Kaisha
30-2, 3-chome, Shimomaruko,
Ohta-ku
Tokyo 146 (JP)

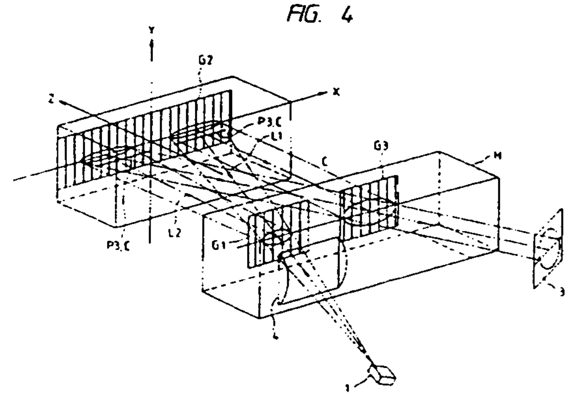
(74) Representative: Tiedtke, Harro, Dipl.-Ing.
Patentanwaltsbüro
Tiedtke-Bühling-Kinne & Partner
Bavariaring 4
D-80336 München (DE)

(54) Optical displacement sensor.

(57) A device for measuring relative displacement information of an object is disclosed. The device is provided with an illumination system (1) for forming an illumination light beam, a light beam splitting element (G1) for splitting the illumination light beam from the illumination system and arranged at a position opposite to the object (G2), a light beam mixing element (G3) for mixing reflected and diffracted light beams by the object of light beams split by the light beam splitting element and arranged at a position opposite to the object in the vicinity of the light beam splitting element, and a light-receiving element (3) for receiving a light beam mixed by the light beam mixing element, relative displacement information of the object being detected based on the light received by the light-receiving element.

The illumination system is arranged to irradiate the light beam onto the light beam splitting element at an angle not perpendicular to the light beam splitting element, and/or said light-receiving element is arranged to receive the light beam from an angle not perpendicular to the light beam mixing element.

FIG. 4



EP 0 672 891 A1

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to an optical displacement sensor which can precisely obtain the physical quantity of movement information such as the moving amount, displacement, or the like of an object by utilizing the fact that interference light beams are modulated by diffraction and interference which occur upon irradiation of light onto an object.

Related Background Art

As a conventional optical displacement sensor of this type, an optical encoder, a laser Doppler velocimeter, a laser interferometer, and the like are available. Although these sensors have high precision and high resolution, a compact structure (on the order of mm), higher precision, higher resolution, (on the order of 0.1 μm), and higher stability are required to attain application to a wider range of fields. If such a sensor has a size on the order of mm, it can be directly adhered to an object to be measured when it is used, and can be used for smaller devices. However, in this case, a mounting error easily occurs, and a countermeasure against such an error must be taken.

In the field of a detection device of movement information utilizing light, the following prior arts are known as ones effective for achieving a compact structure.

Figs. 1A and 1B are explanatory views of an optical encoder disclosed in Japanese Laid-Open Utility Model Application No. 1-180615. Referring to Figs. 1A and 1B, the principle of measurement of this optical encoder is as follows. That is, a light beam emitted from a light-emitting element 42 passes through a hole 46A of a board 46, and is converted into a linear light beam array by a slit array 14. The linear light beam array is irradiated onto a grating on a scale 40. The grating 16 on the scale 40 is projected onto an index grating by the light beam reflected by a bottom surface 12, and the amount of light transmitted through the index grating and incident on a light-receiving element 48 on the board 46 is modulated by geometric overlap between the two gratings. Based on this principle, the encoder can be rendered compact, but its resolution is limited.

Figs. 2A and 2B are explanatory views of an optical encoder disclosed in Japanese Laid-Open Patent Application No. 62-121314, and show one effective improved arrangement for making a basic optical system of an encoder using three diffraction gratings (UK Patent Application GB 1474049 A, Leitz) compact. Referring to Figs. 2A and 2B, a light beam emitted from a light-emitting element 51 is converted into a collimated light beam by a lens 52, and is irradiated onto a grating GK(A) on an index scale A. The irradiated light beam is diffracted by the grating GK(A) and generates light beams in three different exit directions.

These light beams are diffracted by a grating GK(B) on a scale B, are phase-modulated by relative movement, and the modulated light beams return to the grating GK(A) on the index scale A. Upon diffraction by the grating on the index scale, the three pairs of interference light beams are incident on light-receiving elements arranged in different directions. With this arrangement, both a compact structure and high resolution are compatible.

Fig. 3 is an explanatory view of an optical encoder disclosed in Japanese Laid-Open Patent Application No. 3-279812, and shows an example which is effective for simultaneously attaining high precision and a simple compact structure. The encoder shown in Fig. 3 includes a light-emitting element 61, a lens 62, diffraction gratings 63 and 64, and light-receiving elements 65a and 65b.

In the encoders of the above-mentioned prior arts, the optical path of light emitted from a light-emitting source is split into two or more, and interference light of the split beams is received. At this time, since a light beam perpendicularly incident on a split grating is used, and light beams almost perpendicularly emerging from a grating for mixing light beams are used as interference light, diffracted light beams which emerge to the right and left sides of the sensor tend to become stray light beams. In addition, since the above-mentioned arrangement requires a predetermined space between the light source side and the sensor side, a compact structure is difficult to achieve as a whole. Therefore, it is difficult to constitute a displacement sensor which has a further compact structure and higher resolution.

SUMMARY OF THE INVENTION

The present invention has been made in consideration of the above-mentioned prior arts, and has as its first object to provide an optical displacement sensor which can achieve a further compact structure and higher precision.

Other objects of the present invention will become apparent from the following description of the embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1A and 1B are schematic views showing principal part of a conventional optical encoder;

Figs. 2A and 2B are schematic views showing principal part of another conventional optical encoder;

Fig. 3 is a schematic view showing principal part of still another conventional optical encoder;

Fig. 4 is a perspective view showing principal part of the first embodiment of the present invention;

Figs. 5A and 5B are schematic views showing principal part of the first embodiment of the present invention;

Fig. 6 is an explanatory view showing the direction of an azimuth angle in an optical encoder;

Fig. 7 is an explanatory view showing a state wherein interference fringes are generated when a mounting error occurs between the azimuth angles of a head unit and a scale unit in an optical encoder;

Fig. 8 is an explanatory view showing the direction of a rotation angle in an optical encoder;

Fig. 9 is an explanatory view showing a state wherein interference fringes are generated when a mounting error occurs between the rotation angles of a head unit and a scale unit in an optical encoder;

Figs. 10A and 10B are explanatory views showing the relationship among the angle difference between two interference light beams, the azimuth angle, and (wavelength/grating pitch) when a mounting error occurs between the azimuth angles of the head unit and the scale unit;

Figs. 11A and 11B are explanatory views showing the relationship among the angle difference between two interference light beams, the azimuth angle, and (wavelength/grating pitch) when a mounting error occurs between the rotation angles of the head unit and the scale unit;

Figs. 12A and 12B are explanatory views showing the relationship among the crossing point between two interference light beams, the azimuth angle, and (wavelength/grating pitch) when a mounting error occurs between the azimuth angles of the head unit and the scale unit;

Figs. 13A and 13B are explanatory views showing the relationship among the crossing point between two interference light beams, the azimuth angle, and (wavelength/grating pitch) when a mounting error occurs between the rotation angles of the head unit and the scale unit;

Fig. 14 is a perspective view showing principal part of the second embodiment of the present invention;

Figs. 15A and 15B are schematic views showing principal part of the second embodiment of the present invention;

Figs. 16A and 16B are schematic views showing principal part of the third embodiment of the present invention;

Figs. 17A and 17B are schematic views showing principal part of the fourth embodiment of the present invention; and

Figs. 18A and 18B are schematic views showing principal part of the fifth embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 4 is an optical path perspective view showing the first embodiment of an optical displacement sensor according to the present invention, and Figs. 5A and 5B are respectively a plan view (Fig. 5A) and a side view (Fig. 5B) showing the optical path of the first embodiment. Referring to Fig. 4 and Figs. 5A and 5B, the sensor includes a head unit H, a light-emitting element 1, a light-receiving element 3, and a first diffraction grating G1. The first diffraction grating G1 splits a light beam emitted from the light-emitting element 1. A second diffraction grating G2 serves as a scale for phase-modulating a plurality of light beams split by the first diffraction grating G1. A third diffraction grating G3 mixes a plurality of diffracted light beams of predetermined orders from the second diffraction grating. A cylindrical lens 4 as an optical element condenses the light beam from the light-emitting element 1 in only the grating line direction of the first diffraction grating G1.

The light-emitting element 1, the optical element 4, and the first diffraction grating G1 constitute one element of light projection means, the second diffraction grating G2 constitutes one element of modulation means, and the third diffraction grating G3 and the light-receiving element 3 constitute one element of light-receiving means. Note that the light projection means and the light-receiving means constitute one element of the head unit H.

The principle of measurement of relative displacement information between the second and third diffraction gratings G2 and G3 will be explained below. A divergent light beam emitted from the light-emitting element 1 is converted by the cylindrical lens 4 into a wave surface state in that the light beam is convergent in the grating line direction (Y-direction) of the first diffraction grating G1 by the cylindrical lens 4, and is divergent from the light source in the split direction of light beams, i.e., the grating arrangement direction (X-direction) of the first diffraction grating G1. The converted light beam is transmission-diffracted at point O1 on the first diffraction grating G1 to be split into three light beams, i.e., a 0th-order diffracted light beam R_0, a +1st-order diffracted light beam R_{+1}, and a -1st-order diffracted light beam R_{-1}, and these light beams emerge from the first diffraction grating

G1.

In this embodiment, of these light beams, only the 0th- and -1st-order diffracted light beams R_0 and R_{-1} are utilized.

In this embodiment, the light beam from the light-emitting element 1 is incident on the first diffraction grating G1 at the same angle as the diffraction angle of an nth-order (-1st-order) diffracted light beam from the first diffraction grating (i.e., an angle defined with the 0th-order diffracted light beam) as an incident angle.

The light beam R_0 which is transmitted straight through the first diffraction grating G1 is condensed at position C near the second diffraction grating G2 in the grating line direction of the first diffraction grating G1, and is reflected and diffracted at point P2 on the second diffraction grating G2. The diffracted light beam is split into a +1st-order diffracted light beam R_{0+1} and a -1st-order diffracted light beam R_{0-1}, and these light beam are phase-modulated.

In this embodiment, of these light beams, only the -1st-order diffracted light beam R_{0-1} is utilized. The phase of the -1st-order diffracted light beam R_{0-1} is shifted by $-2\pi\Delta x/P$. Note that Δx is the moving amount, in the X-direction, of the second diffraction grating G2, and P is the pitch of the second diffraction grating G2.

The -1st-order diffracted light beam R_{0-1} is transmission-diffracted by the third diffraction grating G3, and is split into a 0th-order diffracted light beam R_{0-10}, a +1st-order diffracted light beam R_{0-1+1}, and other light beams. Of these light beams, the +1st-order diffracted light beam R_{0-1+1} is output from the diffraction grating surface in the 1st-order diffraction direction, and the phase of its wave surface is $-2\pi\Delta x/P$.

The light beam R_{-1}, which is -1st-order-diffracted by the first diffraction grating G1 in a direction perpendicular thereto, is reflection-diffracted at point P1 on the second diffraction grating G2, and is split into a +1st-order diffracted light beam R_{-1+1}, a -1st order diffracted light beam R_{-1-1}, and other light beams. These light beams are phase-modulated. Of these light beams, only the +1st-order diffracted light beam R_{-1+1} is utilized. The phase of the +1st-order diffracted light beam R_{-1+1} is shifted by $+2\pi\Delta x/P$. The +1st-order diffracted light beam R_{-1+1} is condensed in the grating line direction of the first diffraction grating G1 at the position C near the second diffraction grating G2, and is then incident on the third diffraction grating G3. Of the light beams diffracted by the third diffraction grating G3, a 0th-order diffracted light beam R_{-1+10}, which is transmitted straight through the third diffraction grating G3, is utilized. The phase of this wave surface is $+2\pi\Delta x/P$.

In this embodiment, the respective elements are set so that the light beam R_{0-1+1} emerges from the third diffraction grating G3 at an exit angle which is equal to the diffraction angle of an nth-order diffracted light beam by the first diffraction grating G1 of the light beam from the light-emitting element 1.

The light beams R_{-1+10} and R_{0-1+1} whose optical paths are caused to overlap each other by the third diffraction grating G3 are incident on the light-receiving element 3 as interference light. The interference phase at this time is:

$$\{+2\pi\Delta x/P\} - \{-2\pi\Delta x/P\} = 4\pi\Delta x/P$$

Thus, when the second diffraction grating G2 as a scale deviates by a P/2 pitch in the grating arrangement direction, a bright and dark signal for one period is generated.

The relationship among mounting error angles ϕ and η, the angle difference θ between two interference light beams, and (the wavelength λ of light)/(the diffraction grating pitch P) will be explained below.

Referring to Fig. 4, if the vector of a ray of light, which is transmitted through the cylindrical lens 4 and perpendicularly incident on the first diffraction grating G1, of light emitted by the light-emitting element is represented by u_0 (u_{0x}, u_{0y}, u_{0z}), and m is the order of diffraction, a directional vector u_1 (u_{1x}, u_{1y}, u_{1z}) of mth-order light, which is transmission-diffracted by the first diffraction grating G1, is known to satisfy the following relations (Px and Py are respectively the pitches, in the x- and y-directions, of the diffraction grating, and the diffraction grating is present in the x-y plane):

$$(1)\quad \begin{cases} u_{1x} = u_{0x} + m\lambda/Px \\ u_{1y} = u_{0y} + m\lambda/Py \\ u_{0x}^2 + u_{0y}^2 + u_{0z}^2 = 1 \\ u_{1x}^2 + u_{1y}^2 + u_{1z}^2 = 1 \end{cases}$$

Based on this relationship, the angle difference θ between the two light beams R_{-1+10} and R_{0-1+1}, which are transmission-diffracted by the third diffraction grating G3 and interfere with each other, is: (for $\lambda/P = s$))

$$\theta = \mathrm{Cos}^{-1}[(2s)^2(\mathrm{Cos}\eta - 1) + 1]$$

$$\theta = -\phi - \mathrm{Sin}^{-1}\{s + \mathrm{Sin}[\phi - \mathrm{Sin}^{-1}(s)]\} + \mathrm{Sin}^{-1}\{s + \mathrm{Sin}[\phi - \mathrm{Sin}^{-1}(s - \mathrm{Sin}\phi)]\}$$

If θ and ϕ are assumed to be minute angles,

approximations up to the second order are:

$$\theta = 2s\eta \ (\eta\text{: azimuth angle}) \qquad (2)$$

$$\theta = s\phi^2/[(1 - s^2)^{1/2}] \ (\phi\text{: rotation angle}) \qquad (3)$$

When a mounting error (azimuth angle η) shown in Fig. 6 is given, the angle difference θ between the interference two light beams R_{-1+10} and R_{0-1+1} is generated in the y-z plane in Fig. 4 (see Fig. 7). On the other hand, when a mounting error (rotation angle ϕ) shown in Fig. 8 is given, the angle difference θ is generated in the x-z plane in Fig. 4 (see Fig. 9). Figs. 10A and 11A show this relationship. If λ = 0.78 µm and P = 1.6 µm, the relationships shown in Figs. 10B and 11B are obtained.

Then, the position C of the crossing point, viewed from the sensor, between the interference two light beams R_{-1+10} and R_{0-1+1}, when the second diffraction grating G2 suffers a mounting error, is calculated. Upon evaluation using the above-mentioned relationships (1) to (3), and an optical path length L3 from the second diffraction grating G2 to the third diffraction grating G3 (see Figs. 5A and 5B) as a unit length, the crossing point C when the second diffraction grating G2 suffers the azimuth angle η shown in Fig. 6 is as shown in Fig. 12A; the crossing point C when the second diffraction grating G2 suffers the rotation angle ϕ shown in Figs. 11A and 11B is as shown in Fig. 13A. Note that the sign of the crossing point C is defined to be minus in the direction of the sensor and plus in the direction of the second diffraction grating G2 to have the third diffraction grating G3 as an origin.

More specifically, when the second diffraction grating G2 suffers the azimuth angle η, the interference two light beams are separated in the grating line direction of the third diffraction grating, and cross each other in the vicinity of the second diffraction grating when they are viewed from the sensor surface in the direction of the third diffraction grating G3. The crossing point C is a position corresponding to (L1 + L2)/2 where L1 and L2 are the optical path lengths from the second diffraction grating to the third diffraction grating of the two split light beams R_{-1+10} and R_{0-1+1}.

In Figs. 5A and 5B, the optical path length of the light beam R_{-1+1} extending from the point P1 to the point P3 corresponds to L1, and the optical path length of the light beam R_{0-1} extending from the point P2 to the point P3 corresponds to L2.

When the third diffraction grating G3 suffers the rotation angle ϕ, the interference two light beams are separated in the grating arrangement direction of the third diffraction grating G3, and appear to cross each other at a very far point when they are viewed in a direction opposite to the direction of the third diffraction grating G3 from the sensor surface 3. If P = 1.6 µm and λ = 0.78 µm, the crossing point C between the interference two light beams is as shown in Figs. 12B and 13B.

In order to stabilize the interference state between the two light beams, the two beams are condensed in the vicinity of the second diffraction grating G2 in the grating line direction of the first diffraction grating G1 (this condensing position is set to match the crossing point C in Fig. 4; that is, the position of L3 = (L1 + L2)/2), and are collimated beams (plane waves) or spherical waves with a very large radius of curvature (divergent light from the light-emitting element in this case) in the grating arrangement direction of the first diffraction grating G1.

As can be seen from Figs. 11A and 11B, even when the rotation angle ϕ is given to the second diffraction grating G2, the angle difference θ between the interference two light beams does not become so large, but the two light beams are separated from each other. For this reason, when the two light beams are spherical waves with a small radius of curvature in this direction, interference fringes tend to form, and the interference state is not stable. However, if the two light beams are plane waves or spherical waves with a very large radius of curvature (spherical waves with a very large radius of curvature which can be regarded as plane waves), the angle difference θ between the two light beams does not become so large, interference fringes do not easily form, and the interference state is stabilized.

Therefore, when the two light beams have a wave surface state with a large radius of curvature, at which the wave surface can be substantially regarded as a plane, or have a radius of curvature approximate thereto, in the grating arrangement direction of the first diffraction grating G1, the interference fringes do not easily form, and the interference state is stabilized.

As for the grating line direction of the first diffraction grating G1, as can be seen from Figs. 12A and 12B, in a region of $\lambda/P < 0.8$, the crossing point C between the two light beams is almost constant regardless of the azimuth angle η. However, as can be seen from Figs. 10A and 10B, the angle difference θ between the interference two light beams increases in proportion to the azimuth angle η.

As can be understood from the above description, when the condensing direction the light beam emitted from the light-emitting element 1 is set to be the grating line direction of the first diffraction grating G1, and the condensing position is set in the same region as the crossing point C between the interference light beams, the wave surfaces of the two light beams overlap each other even when

the angle difference θ between the two light beams is large, and the optical path lengths L1 and L2 become always constant irrespective of the azimuth angle η. For this reason, the interference fringes do not easily form, and the interference state is stabilized.

In this embodiment, since unnecessary diffracted light is generated on the side of the position of the light-emitting element 1 of the sensor 3, an arrangement for shielding stray light can be easily adopted.

In this embodiment, for the above-mentioned reasons, since the two light beams are set to be divergent light from the light source in the grating arrangement direction of the first diffraction grating G1, the radius of curvature of each of the light beams is set as large as possible, and the light beams are set to be convergent light in the grating line direction, an encoder whose output is insensitive to the rotation angle and the azimuth angle, and which is easy to handle can be realized.

In the first embodiment, the entire interference optical system is very simple, and since the head unit is constituted by only the light-emitting element 1, the light-receiving element 3, the cylindrical lens 4, the first diffraction grating G1, and the third diffraction grating G3, its structure is simple and has a small number of components, thus allowing easy assembling. Furthermore, as shown in Fig. 4 and Figs. 5A and 5B, since the first and third diffraction gratings G1 and G3 and the cylindrical lens 4 are formed on a single board, the number of components can be further reduced, thereby realizing a low-cost, very compact structure.

Since the emitted light beam is condensed in the grating line direction of the first diffraction grating G1, and is set to be divergent light (a spherical wave with a very large radius of curvature) from the light-emitting element 1 in the grating arrangement direction, an optical system whose interference state depends on the angle error between the scale G2 and the head unit can be realized, and a compact encoder which is easy to handle can be provided.

Furthermore, since light beams, in the direction of 1st-order diffraction, of those perpendicularly incident on the third diffraction grating G3 for synthesizing the interference two light beams are utilized, signal light (interference two light beams) can be easily isolated from other unnecessary diffracted light components which are transmission-diffracted by the third diffraction grating G3 for synthesizing the interference two light beams.

Since the light-emitting element 1 and the sensor 3 can be easily spatially separated, and an arrangement for shielding unnecessary light, which is emitted from the light-emitting element 1 and reaches the sensor 3, can be easily adopted, an encoder, which can obtain a noise-less signal with a high S/N ratio, can be easily realized.

Fig. 14 is a perspective view showing the second embodiment in which the present invention is applied to an optical displacement sensor, and Figs. 15A and 15B are respectively a plan view and a side view showing the optical paths of the sensor. The same reference numerals in Fig. 14 and Figs. 15A and 15B denote the same parts as in Fig. 4 and Figs. 5A and 5B.

A toric lens 4 condenses a divergent light beam emitted by the light-emitting element 1.

The principle and basic arrangement of the optical system are the same as those in the first embodiment. The wave surface state of a light emitted by the light-emitting element 1 is adjusted to be a cylindrical surface shape by the single optical element 4. Thus, the light beam can be convergent light in the grating line direction, and collimated light in the grating arrangement direction.

In addition to the effect of the first embodiment, the second embodiment can provide the following effect. More specifically, since the wave surface state of a light beam emitted by the light-emitting element 1 is adjusted to be a cylindrical surface shape by a single lens, a compact, low-cost encoder which has a simple structure and is easy to assemble can be realized.

Since the light-emitting element 1 and the light-receiving element 3 are spatially separated, stray light from the light-emitting element 1 can be easily shielded, and a noise-less signal with a high S/N ratio can be obtained.

In each of the above embodiments, a Fresnel lens may be used as the optical element.

Figs. 16A and 16B are respectively a plan view and a side view showing the third embodiment in which the present invention is applied to an optical displacement sensor. The same reference numerals in Figs. 16A and 16B denote the same parts as in Figs. 5A and 5B. In Figs. 16A and 16B, a collimator lens 5 collimates a light beam emitted by the light-emitting element to substantially collimated light, and a cylindrical lens 4 condenses the light beam in the grating line direction.

The principle and basic arrangement of the optical system are the same as those in the second embodiment. A light beam emitted by the light-emitting element 1 is incident on the diffraction grating G1 at an arbitrary angle θ which is equal to neither a right angle nor the diffraction angle of nth-order diffracted light.

In addition to the effects of the first and second embodiments, the third embodiment can provide the following effect. Since a light beam emitted by the light-emitting element 1 is incident on the diffraction grating at an arbitrary angle θ other than a

right angle, the light source 1 and the light-receiving element 3 can be separated from each other to eliminate the influence of light other than interference light emitted by the light source, and the distance between the scale and head can be shortened, thus realizing a further compact, low-profile structure. Furthermore, since the diffraction grating G3 for mixing light beams and the light-receiving element 3 are arranged to be shifted from each other, the influence of diffracted light other than diffracted light to be used, which emerges from the grating G3 can be eliminated, and a signal with a high S/N ratio can be obtained.

Figs. 17A and 17B are respectively a plan view and a side view showing the fourth embodiment in which the present invention is applied to an optical displacement measurement device. The same reference numerals in Figs. 17A and 17B denote the same parts as in the above embodiments.

In this embodiment, a toric lens 4 condenses a divergent light beam emitted by the light-emitting element in the grating line direction of the diffraction grating G1, and adjusts it to be substantially collimated light in the grating arrangement direction. A light shielding wall 5 shields unnecessary light from the light source. Note that the moving direction of the scale is represented by 6.

The principle and basic arrangement of the optical system are the same as those in the first embodiment. In this embodiment, a light beam from the light source is perpendicularly incident on the diffraction grating G1.

In addition to the effects of the first to third embodiments, this embodiment can provide the following effects.

1) As a light beam to be incident on the light-receiving element, not a light beam which is mixed by the diffraction grating G3 and perpendicularly emerges therefrom, but only a light beam which is diffracted in a direction opposite to the light source is utilized. For this reason, other diffracted light components generated by the diffraction grating G3 can be prevented from becoming incident on the light-receiving element, and a noise-less signal with a high S/N ratio can be output.

2) Since the light source is arranged perpendicularly to the diffraction grating G1, a compact, low-cost encoder which is easy to assemble can be realized.

Figs. 18A and 18B are respectively a plan view and a side view showing the fifth embodiment in which the present invention is applied to an optical displacement measurement device. The same reference numerals in Figs. 18A and 18B denote the same parts as in the above embodiments.

The principle of the optical system will be described below.

A light beam emitted by the light-emitting element 1 is incident on the toric lens 4, and is converted into a light beam which becomes collimated light in the grating arrangement direction and becomes convergent light in the grating line direction. The converted light beam is incident on the diffraction grating G1. The light beam incident on the diffraction grating G1 is split into two light beams, i.e., an nth-order diffracted light beam which is perpendicularly output from the grating surface, and an mth-order diffracted light beam ($n < m$) which has the same exit angle as the diffraction angle generated when perpendicular light is incident on the lines of the diffraction gratings G2 and G3 (the shape (pitch, duty, and the like) of the lines of the diffraction grating G1 is determined so that the light beam with such a diffraction angle has a higher intensity), and these light beams are incident on the diffraction grating G2.

The other principle and basic arrangement are the same as those in the first embodiment.

In the arrangement of this embodiment, as described above, the incident optical path to the diffraction grating G1 and the light-receiving optical path from the diffraction grating G3 to the light-receiving element 3 cross each other, and the light-shielding wall 5 is arranged not to shield these optical paths.

In addition to the effects of the first to third embodiments, the fifth embodiment can provide the following effect.

The light-receiving element and the light-emitting element can be arranged to be separated by a smaller distance than in the above embodiments, and a compact encoder which is easy to assemble and can output a noise-less signal with a high S/N ratio can be realized.

In each of the above embodiments, a Fresnel lens, hologram element, or the like may be used as the optical element.

In the first embodiment, the light-receiving optical path from the diffraction grating G3 to the light-receiving element 3 may extend perpendicularly to the diffraction grating G3. This arrangement is also effective to realize a compact structure.

According to each of the above-mentioned embodiments, when the respective elements are set as described above, an optical displacement sensor, which can easily shield unnecessary light which is emitted by the light-emitting element and reaches the sensor, can obtain a noise-less signal with a high S/N ratio, can obtain displacement information with high precision, and can be rendered compact, can be realized.

A device for measuring relative displacement information of an object is disclosed. The device is provided with an illumination system for forming an illumination light beam, a light beam splitting ele-

ment for splitting the illumination light beam from the illumination system and arranged at a position opposite to the object, a light beam mixing element for mixing reflected and diffracted light beams by the object of light beams split by the light beam splitting element and arranged at a position opposite to the object in the vicinity of the light beam splitting element, and a light-receiving element for receiving a light beam mixed by the light beam mixing element, relative displacement information of the object being detected based on the light received by the light-receiving element.

The illumination system is arranged to irradiate the light beam onto the light beam splitting element at an angle not perpendicular to the light beam splitting element, and/or said light-receiving element is arranged to receive the light beam from an angle not perpendicular to the light beam mixing element.

Claims

1. A device for measuring relative displacement information of an object, comprising:

   an illumination system for forming an illumination light beam; a light beam splitting element for splitting the illumination light beam from said illumination system, said light beam splitting element being arranged at a position opposite to the object; a light beam mixing element for mixing reflected and diffracted light beams by the object of light beams split by said light beam splitting element, said light beam mixing element being arranged at a position opposite to the object in the vicinity of said light beam splitting element; and a light-receiving element for receiving a light beam mixed by said light beam mixing element, relative displacement information of the object being detected based on the light received by said light-receiving element,

   characterized in that said illumination system is arranged to irradiate the light beam onto said light beam splitting element at an angle not perpendicular to said light beam splitting element, and/or said light-receiving element is arranged to receive the light beam from an angle not perpendicular to said light beam mixing element.

2. A device according to claim 1, characterized in that said light beam splitting element and said light beam mixing element comprise diffraction gratings.

3. A device according to claim 1, characterized in that said light beam splitting element and said light beam mixing element are arranged on a single board.

4. A device according to claim 1, characterized by further comprising:

   an optical element for shaping the light beams split by said light beam splitting element, so that the light beams diverge in a splitting direction and converge in a direction perpendicular to the splitting direction.

5. A device according to claim 4, characterized in that said optical element comprises a cylindrical lens arranged on a light beam incidence side of said light beam splitting element.

6. A device according to claim 1, characterized by further comprising:

   an optical element for shaping the light beams split by said light beam splitting element, so that the light beams are collimated in a splitting direction and are condensed in a direction perpendicular to the splitting direction.

7. A device according to claim 6, characterized in that said optical element comprises a toric lens arranged on a light beam incidence side of said light beam splitting element.

8. A device according to claim 6, characterized in that said optical element comprises an optical unit which is arranged on a light beam incidence side of said light beam splitting element and is constituted by a cylindrical lens and a collimator lens.

9. A device according to claim 1, characterized in that said illumination system is arranged to perpendicularly irradiate the light beam onto said light beam splitting element, and said light-receiving element is arranged to receive the light beam from an angle not perpendicular to said light beam synthesizing element.

10. A device according to claim 1, characterized in that an illumination optical path of said illumination system and a light-receiving optical path of said light-receiving element cross each other.

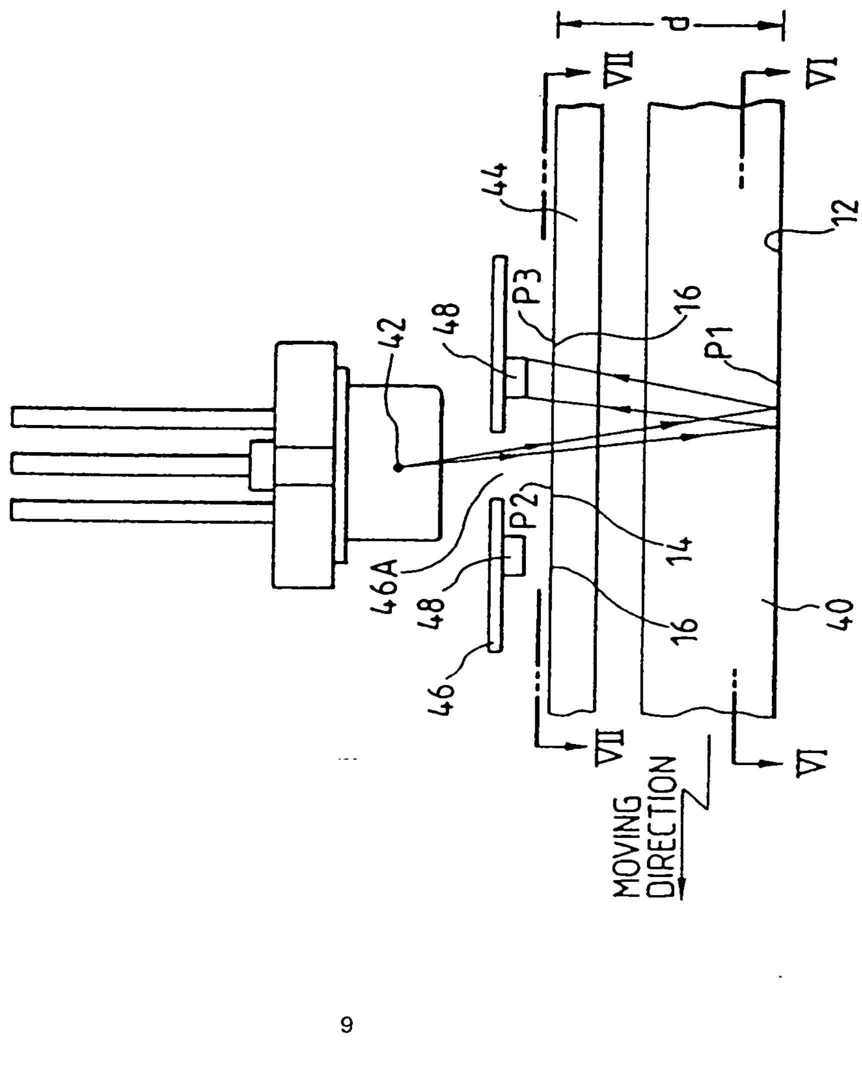


FIG. 1A
PRIOR ART

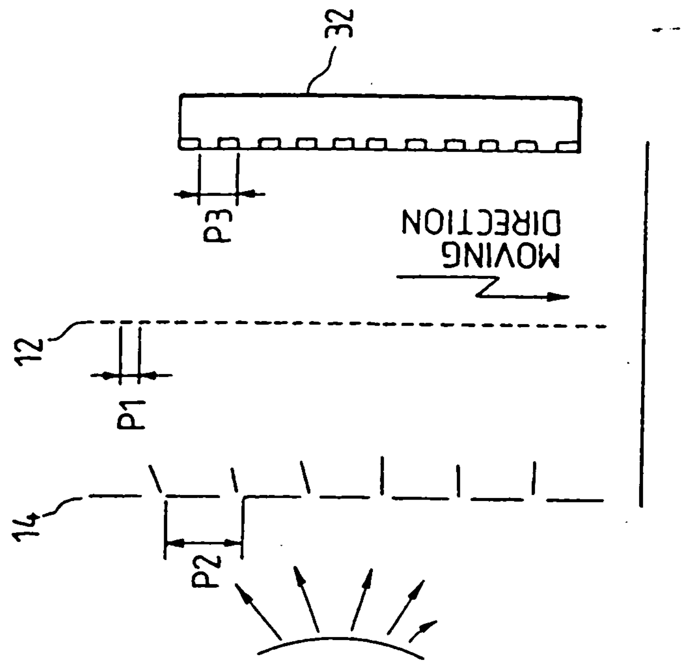


FIG. 1B
PRIOR ART

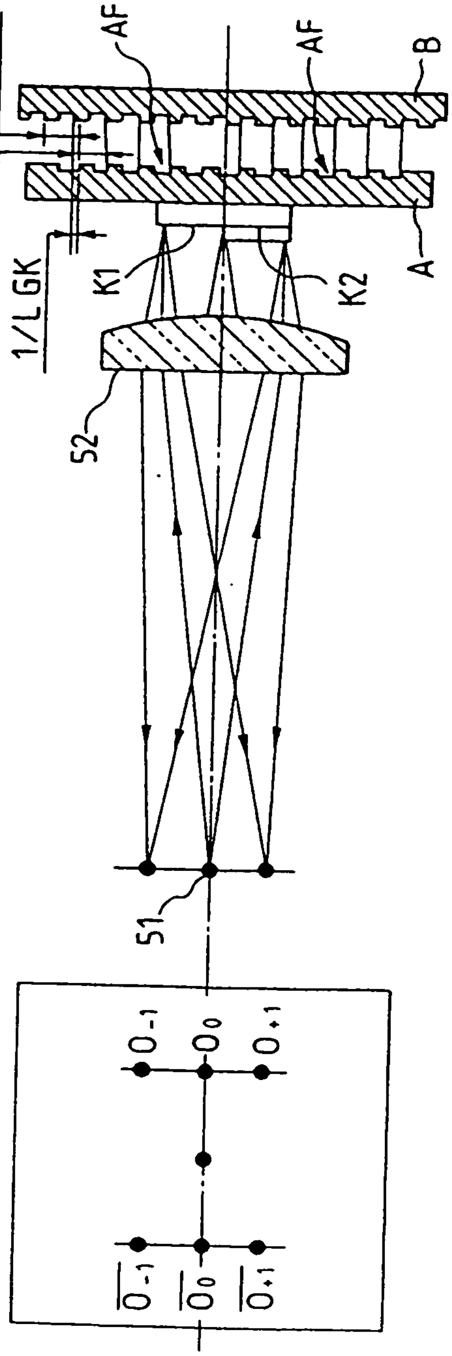


FIG. 2A PRIOR ART

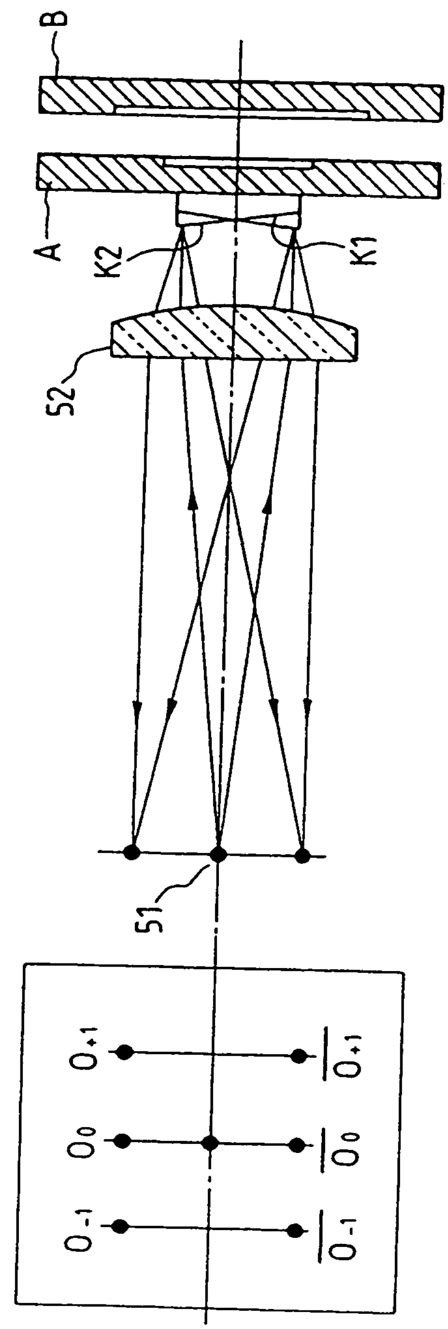


FIG. 2B PRIOR ART

FIG. 3
PRIOR ART

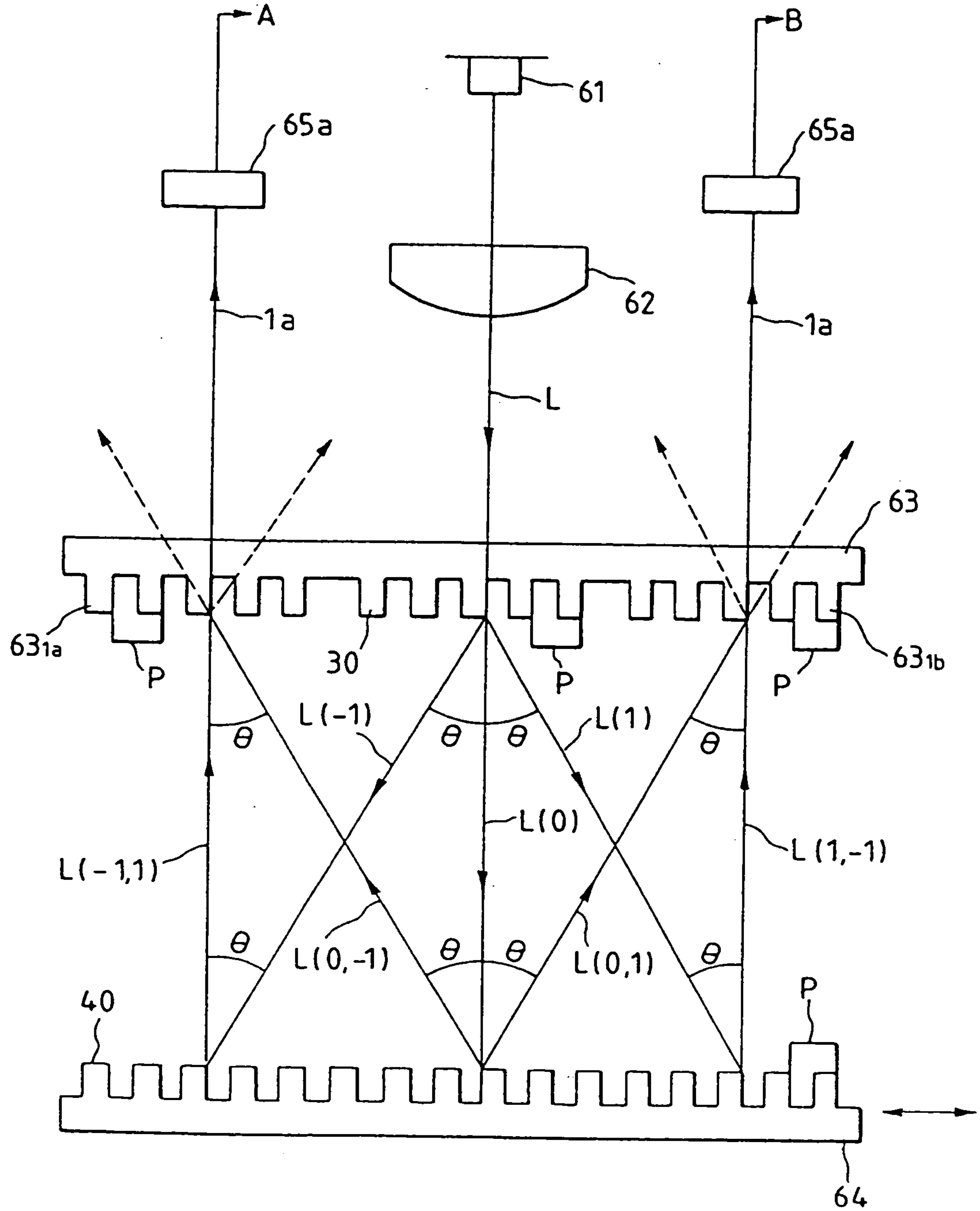
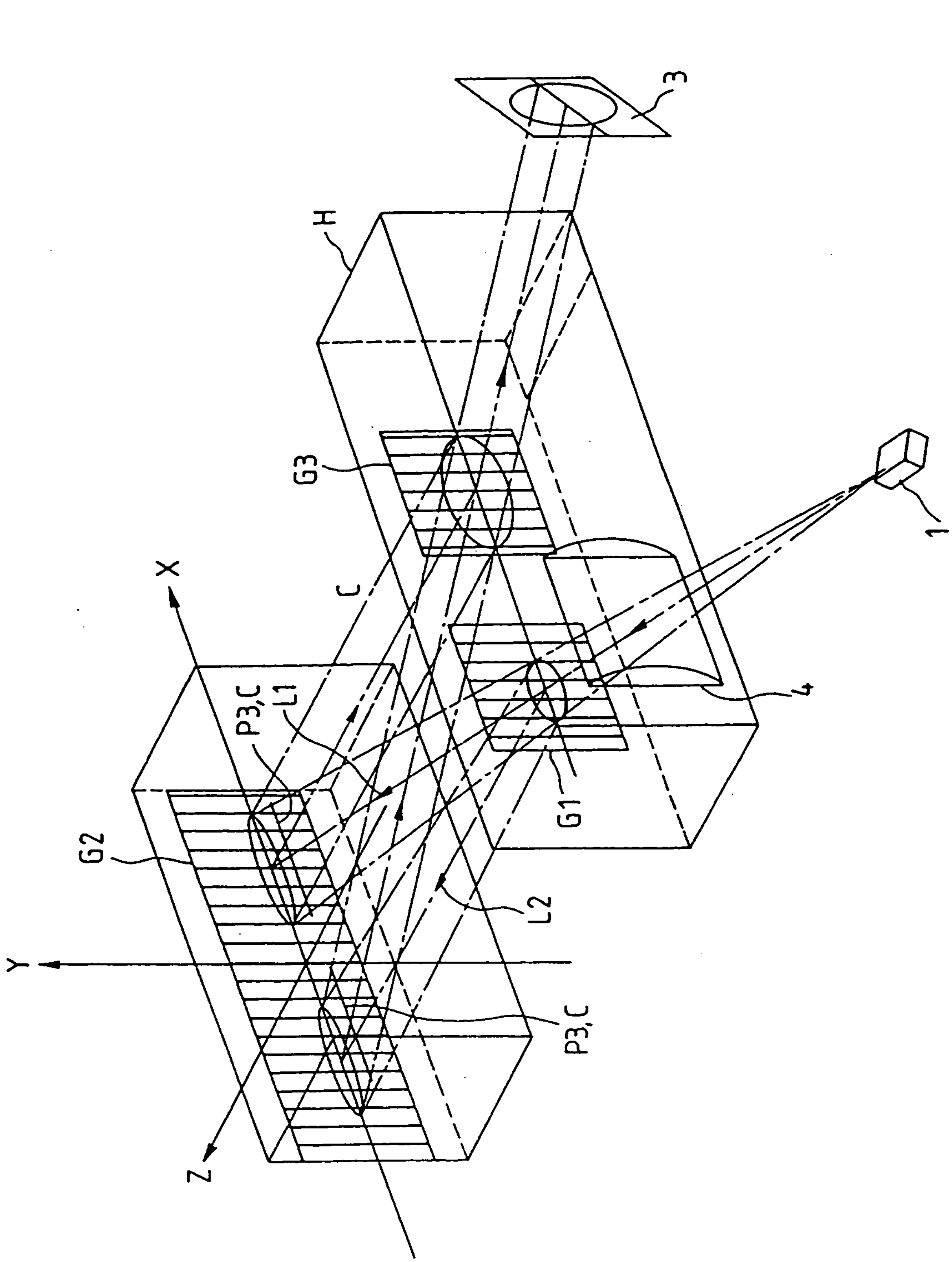


FIG. 4



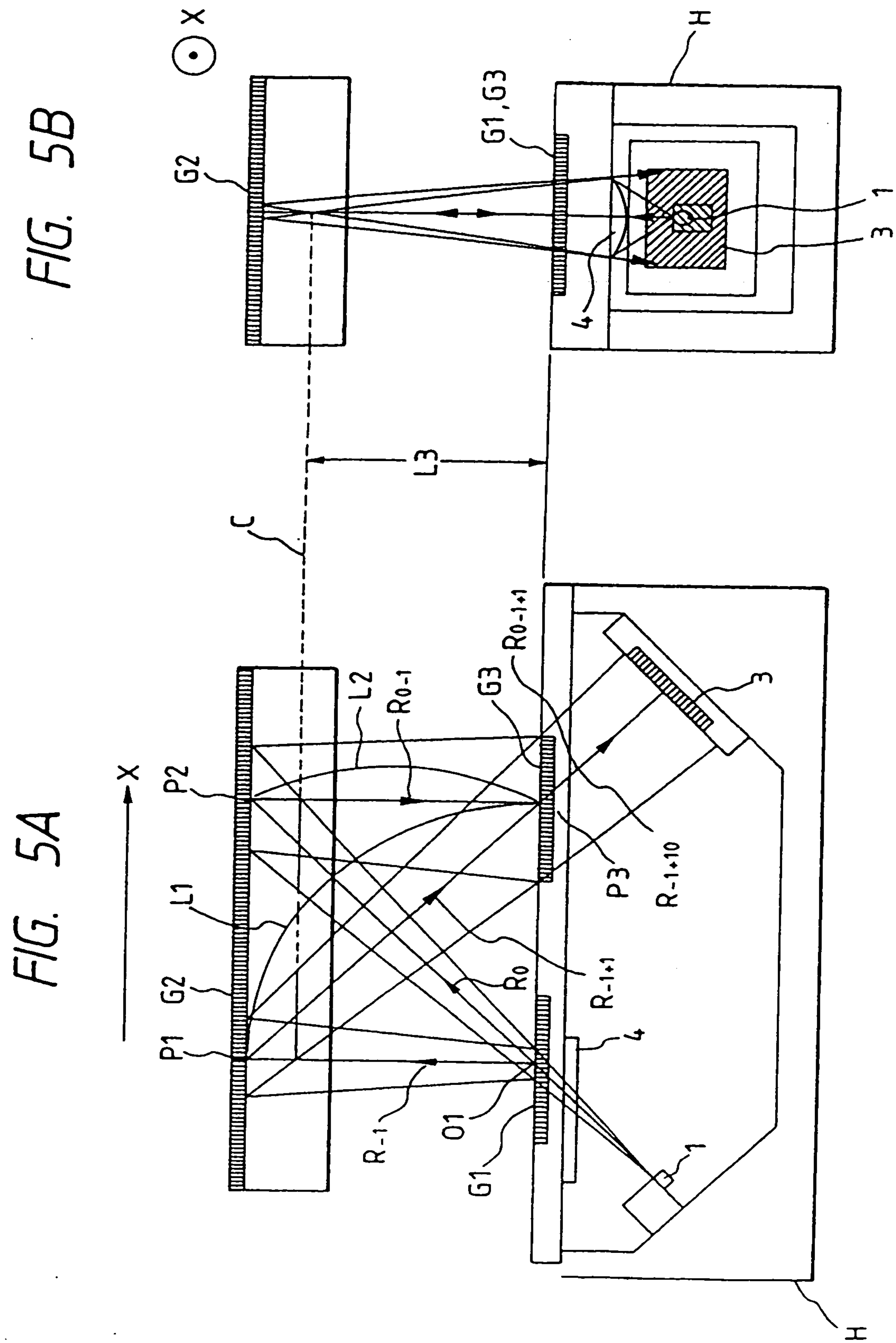


FIG. 5B
X
G2
G1,G3
H
1
3
4
L3
C
FIG. 5A
X
P1
G2
L1
P2
L2
R0-1
G3
R0-1+1
3
P3
R-1+10
R-1+1
R0
R-1
O1
G1
4
1
H

FIG. 6

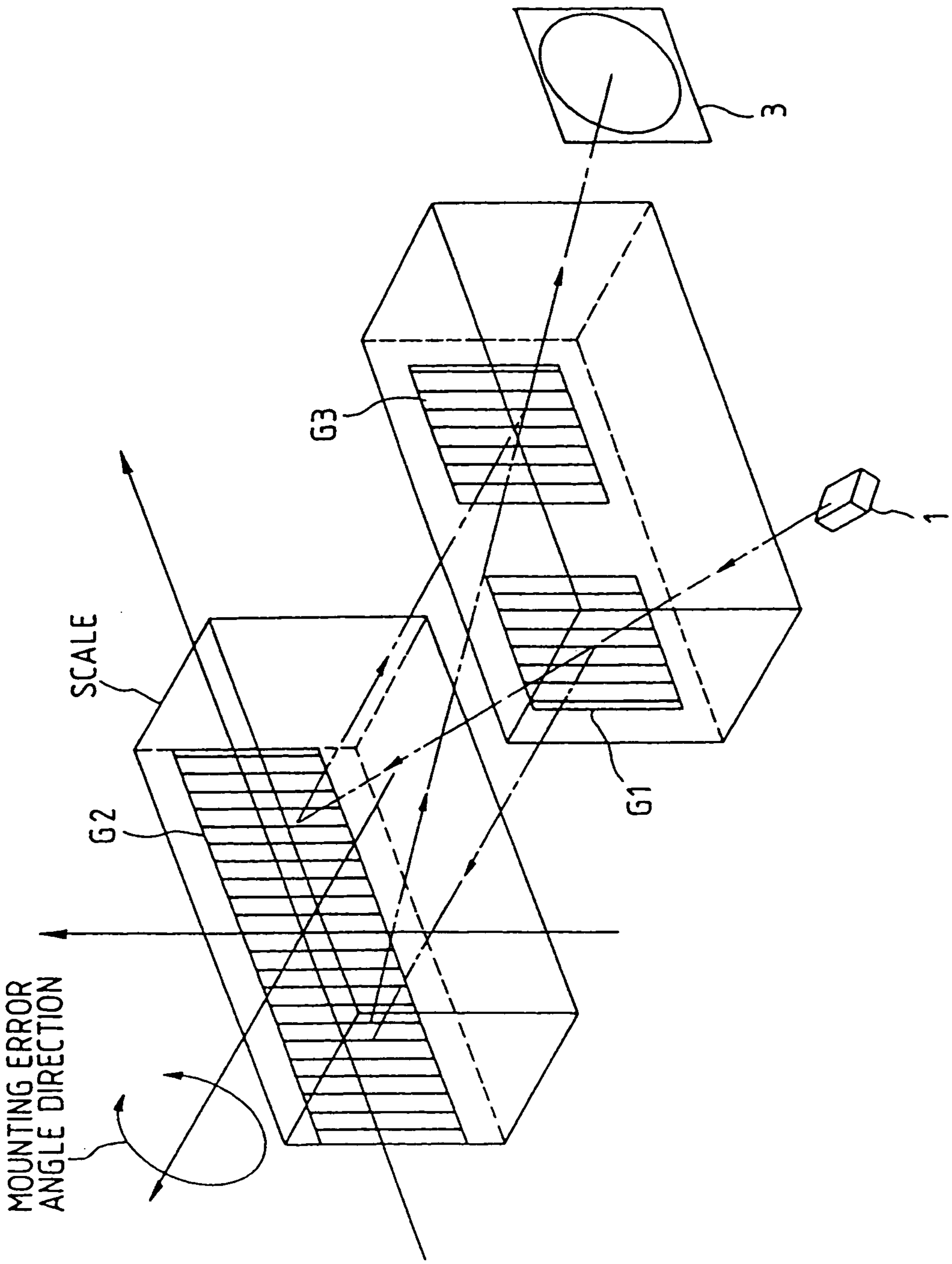


FIG. 7

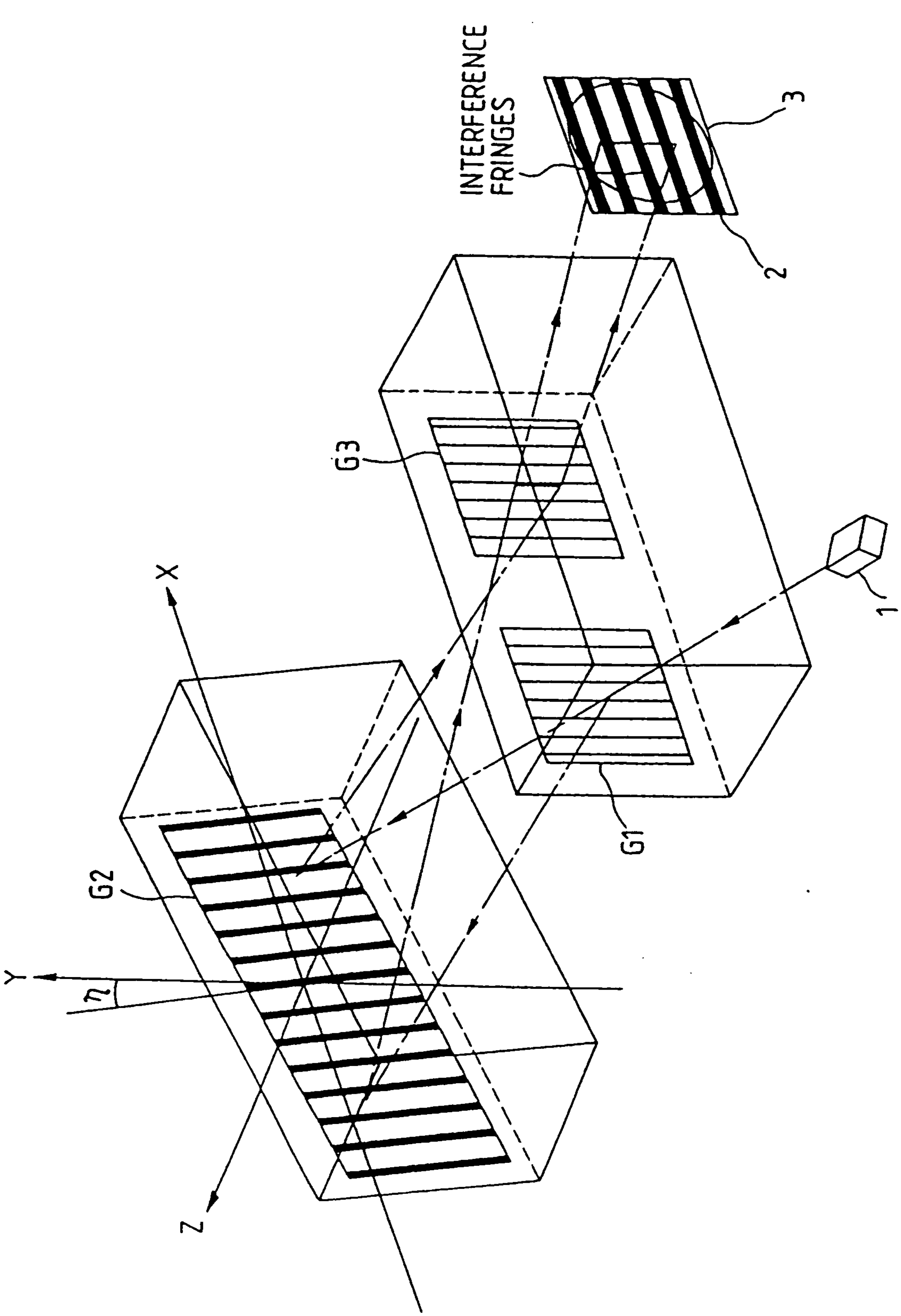


FIG. 8

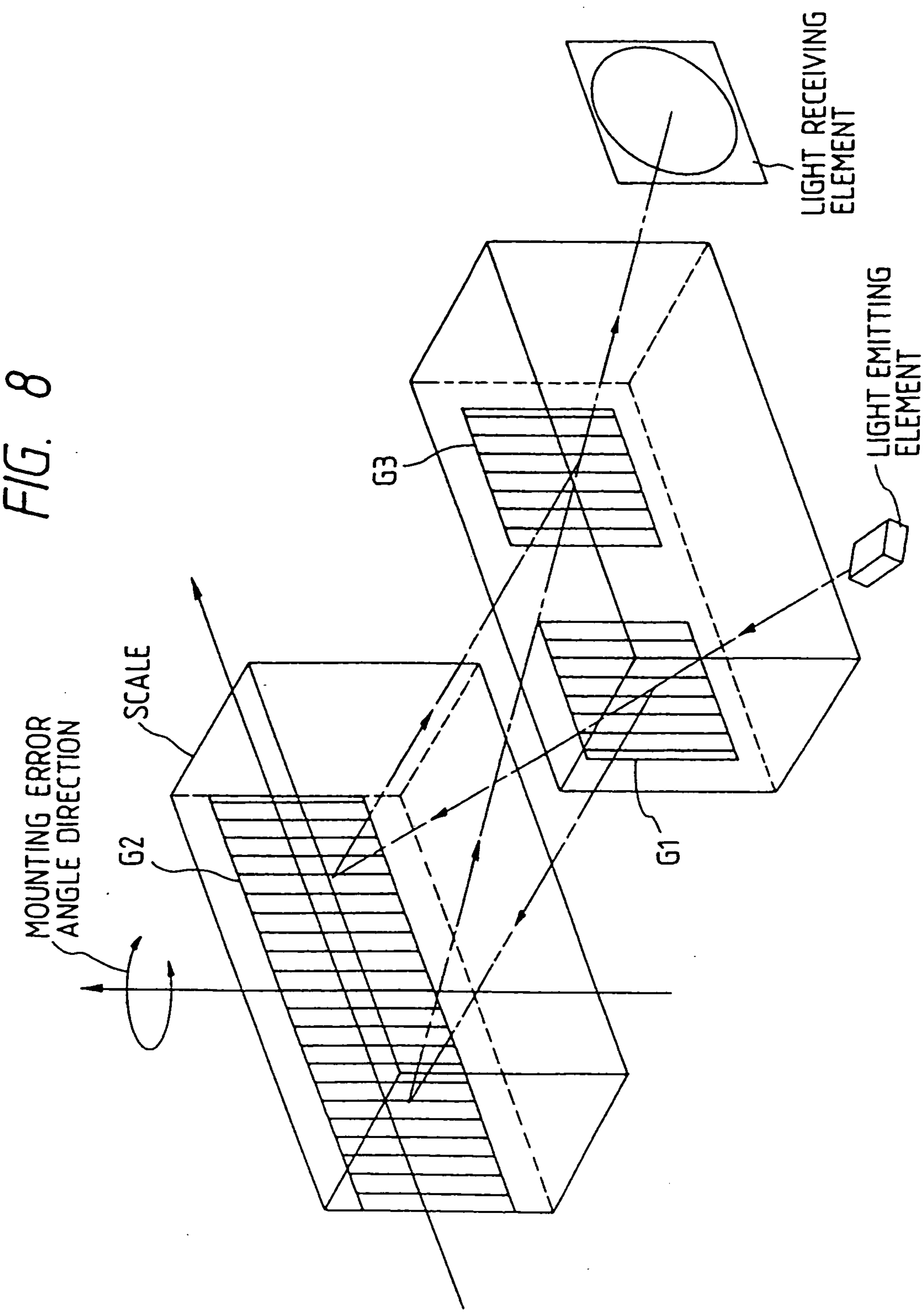

LIGHT RECEIVING ELEMENT
LIGHT EMITTING ELEMENT
G3
G1
G2
SCALE
MOUNTING ERROR ANGLE DIRECTION

FIG. 9

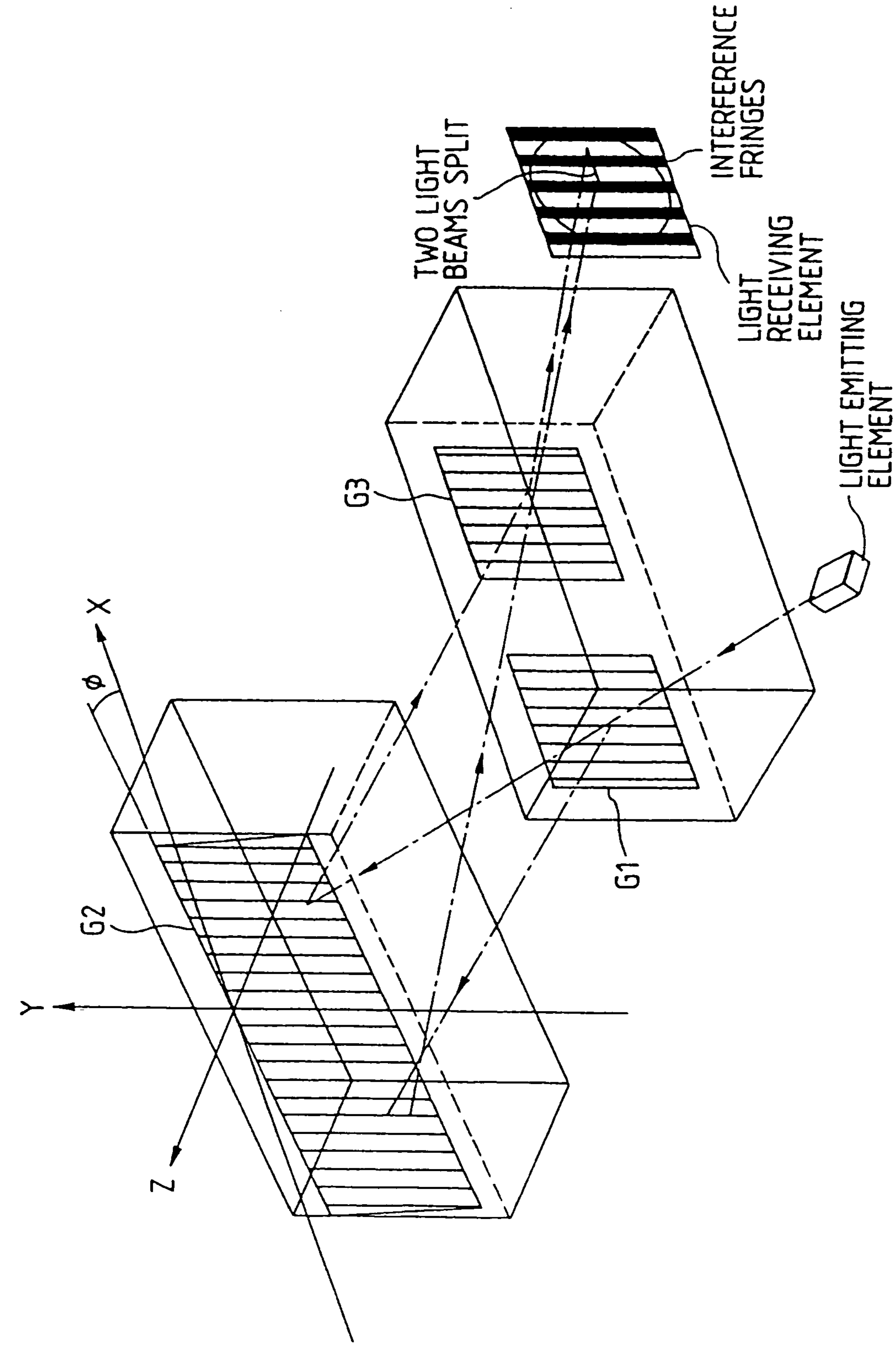

TWO LIGHT
BEAMS SPLIT
INTERFERENCE
FRINGES
LIGHT
RECEIVING
ELEMENT
LIGHT EMITTING
ELEMENT
G3
G2
G1
X
Y
Z
ϕ

FIG. 10A

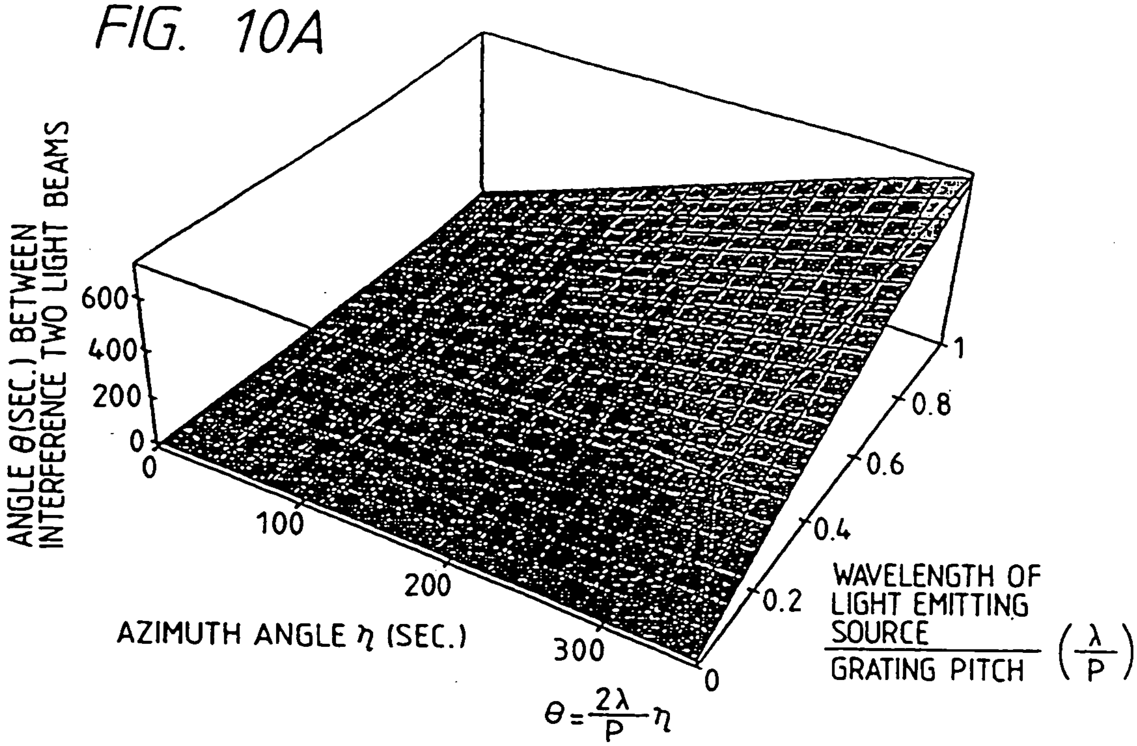


FIG. 10B

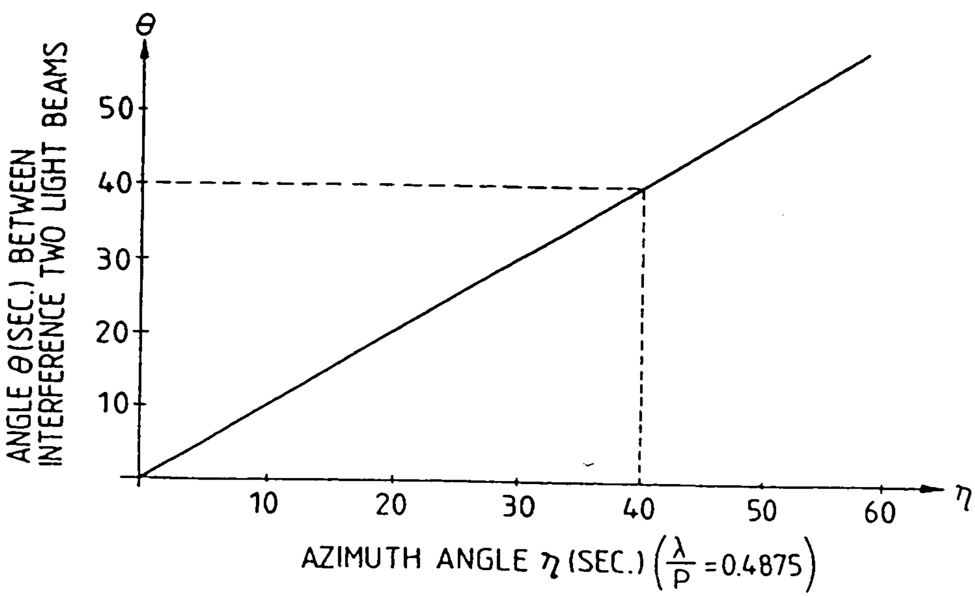


FIG. 11A

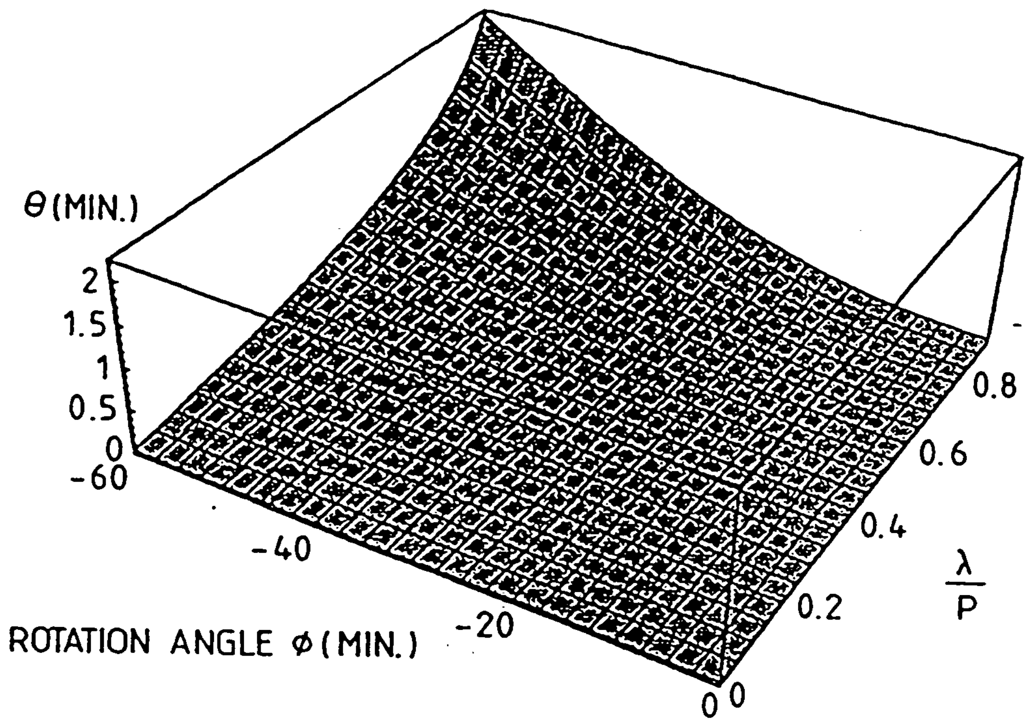


FIG. 11B

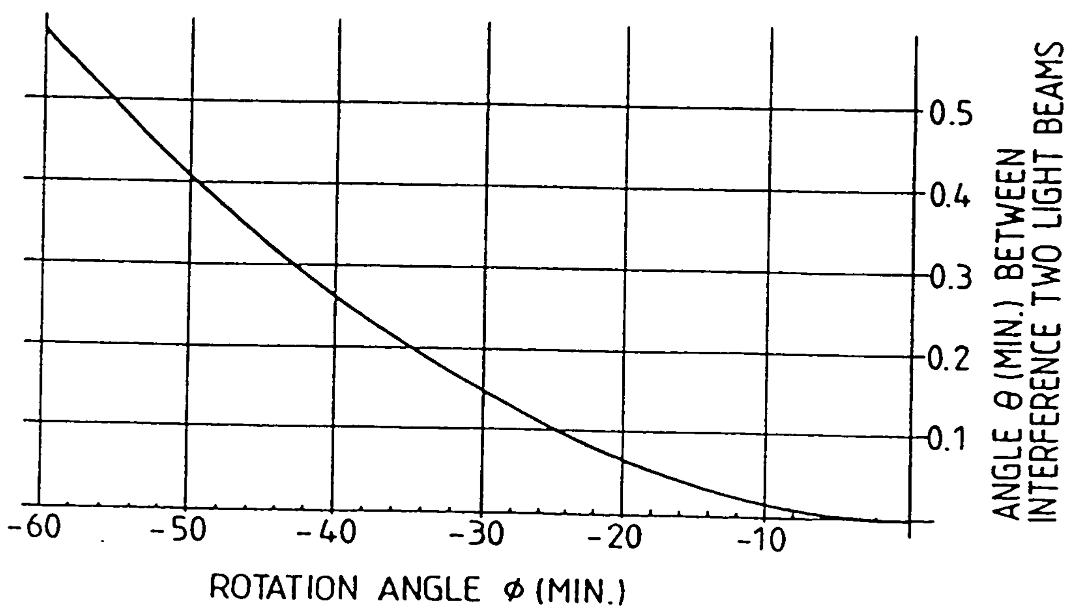


FIG. 12A

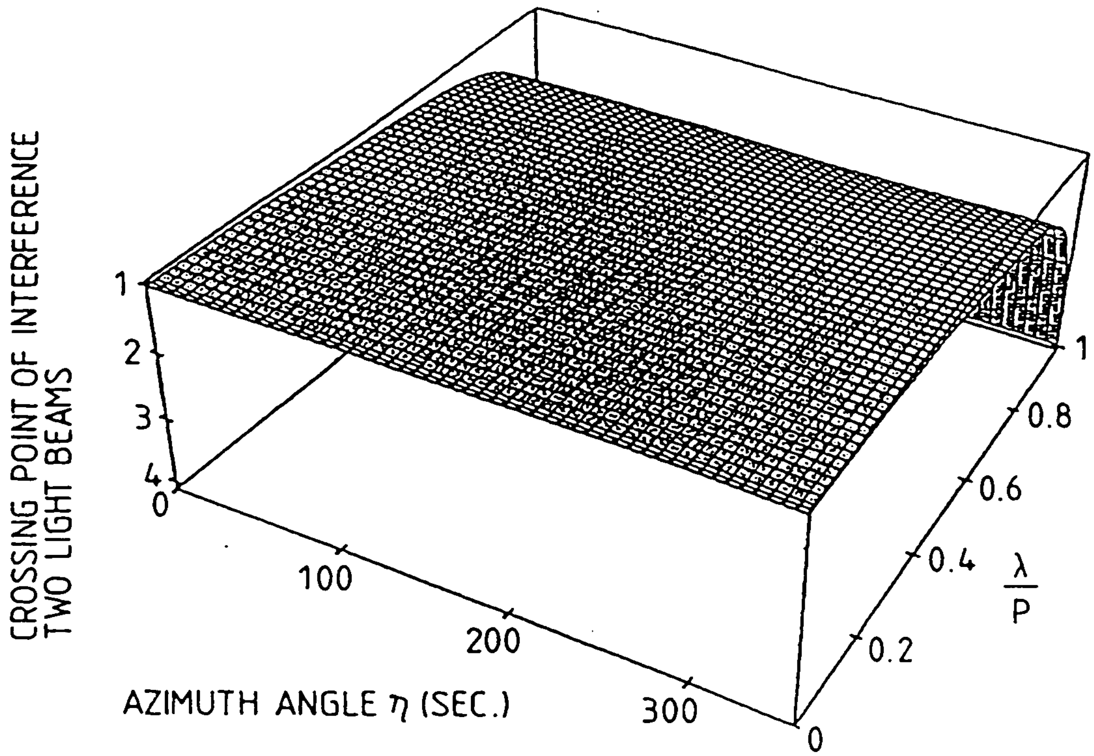


FIG. 12B

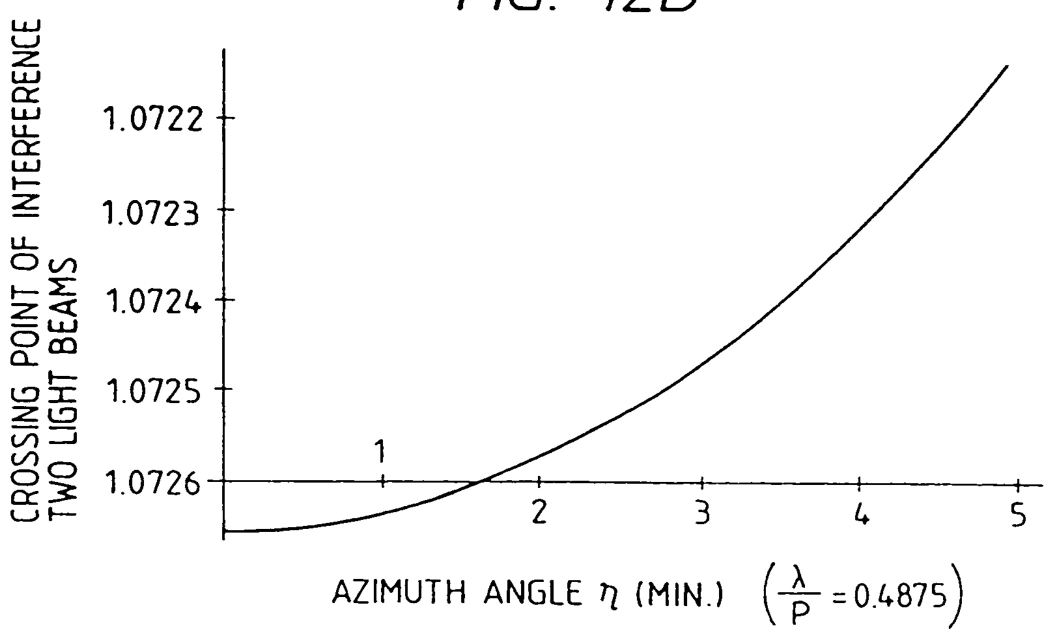


FIG. 13A

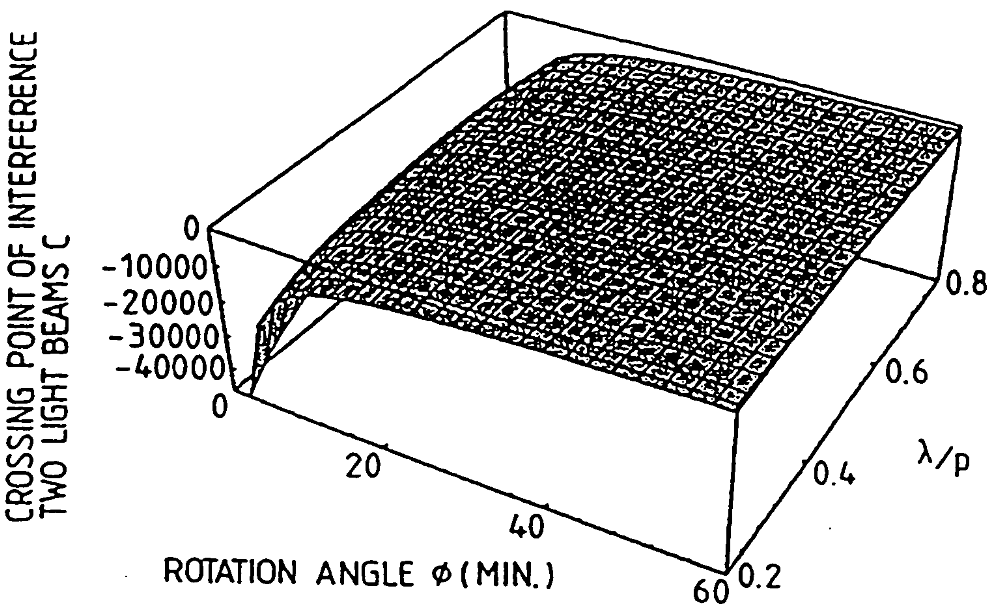


FIG. 13B

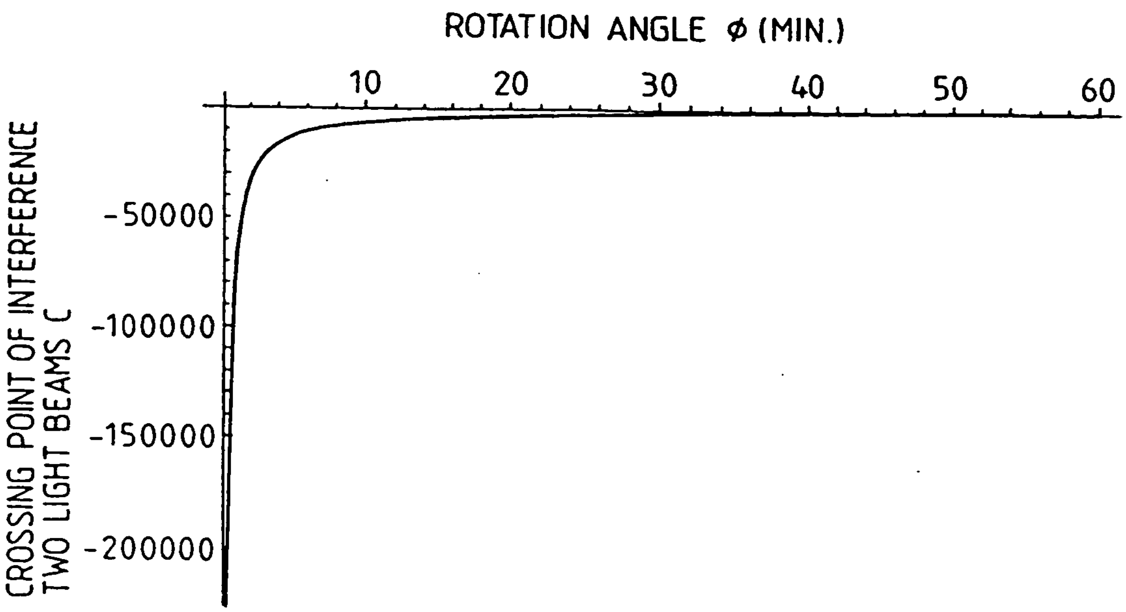
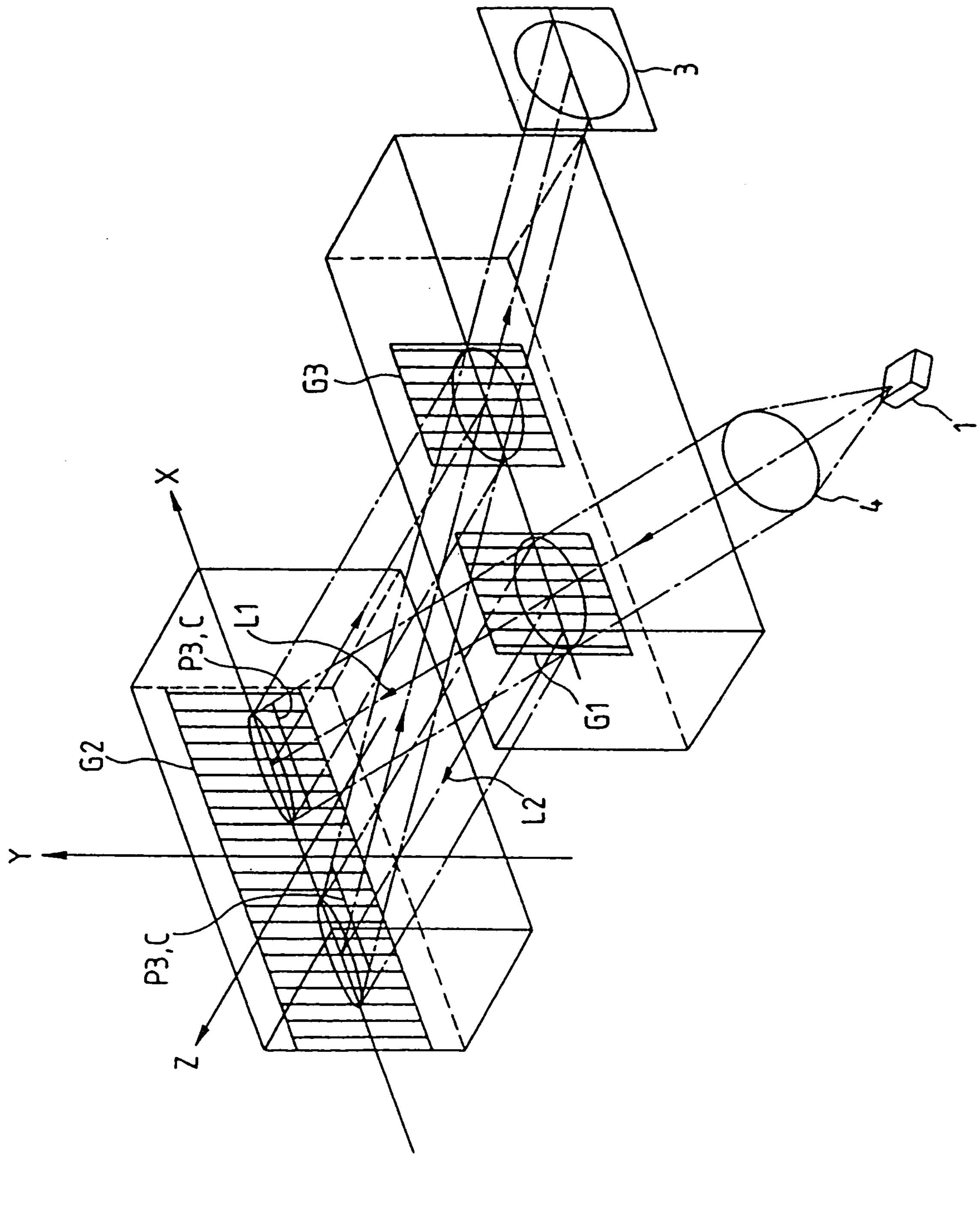


FIG. 14



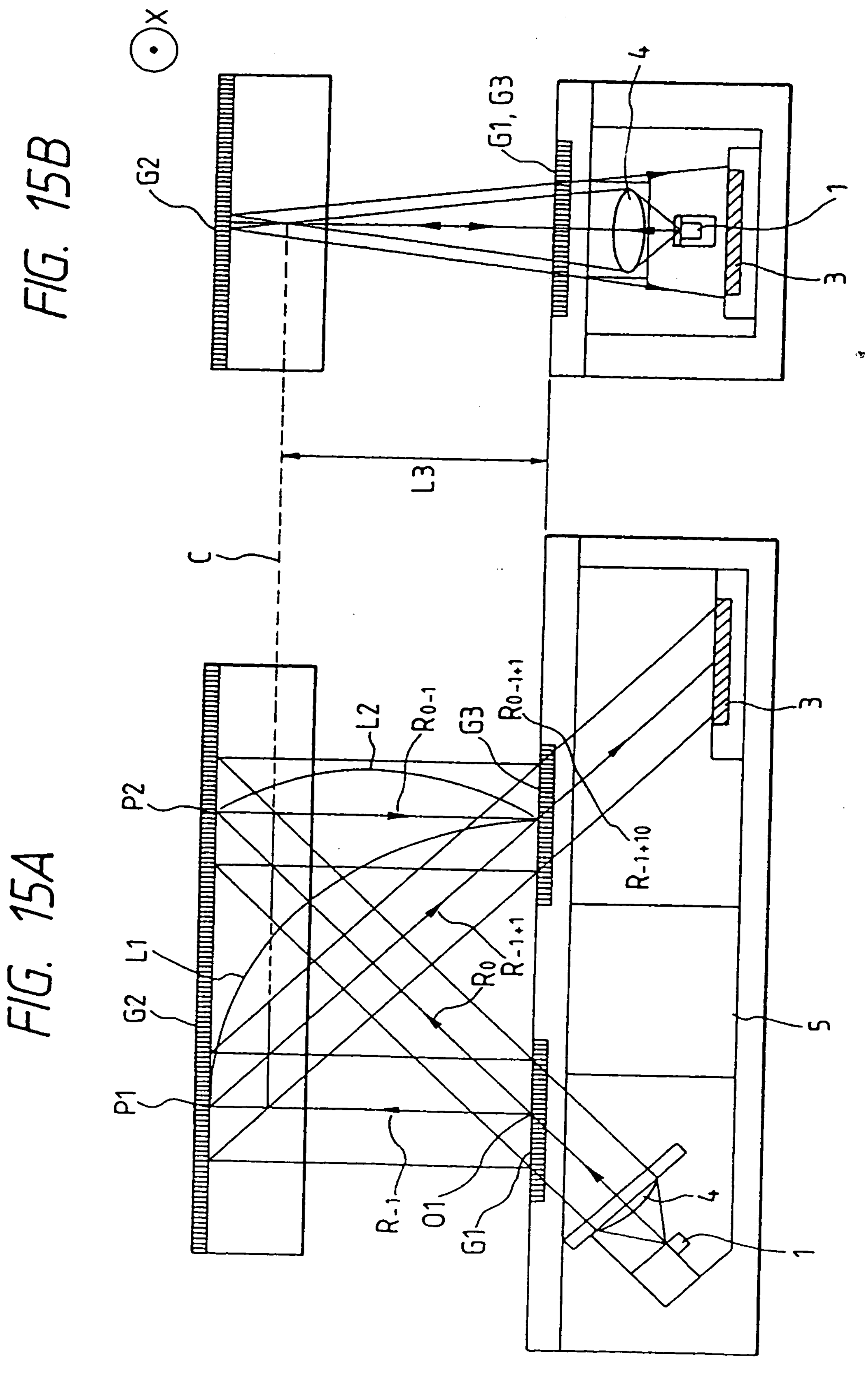


FIG. 15A

FIG. 15B

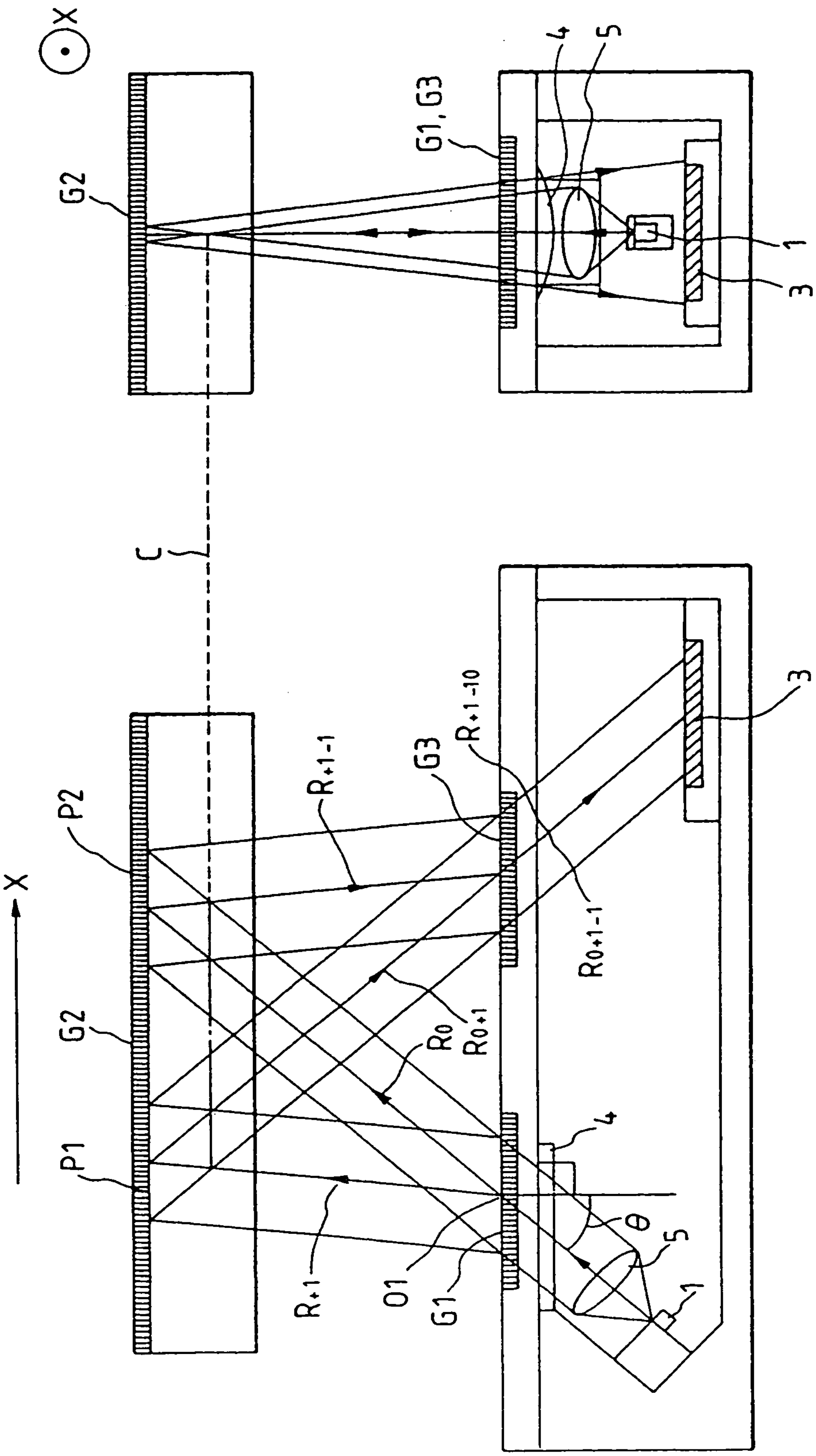
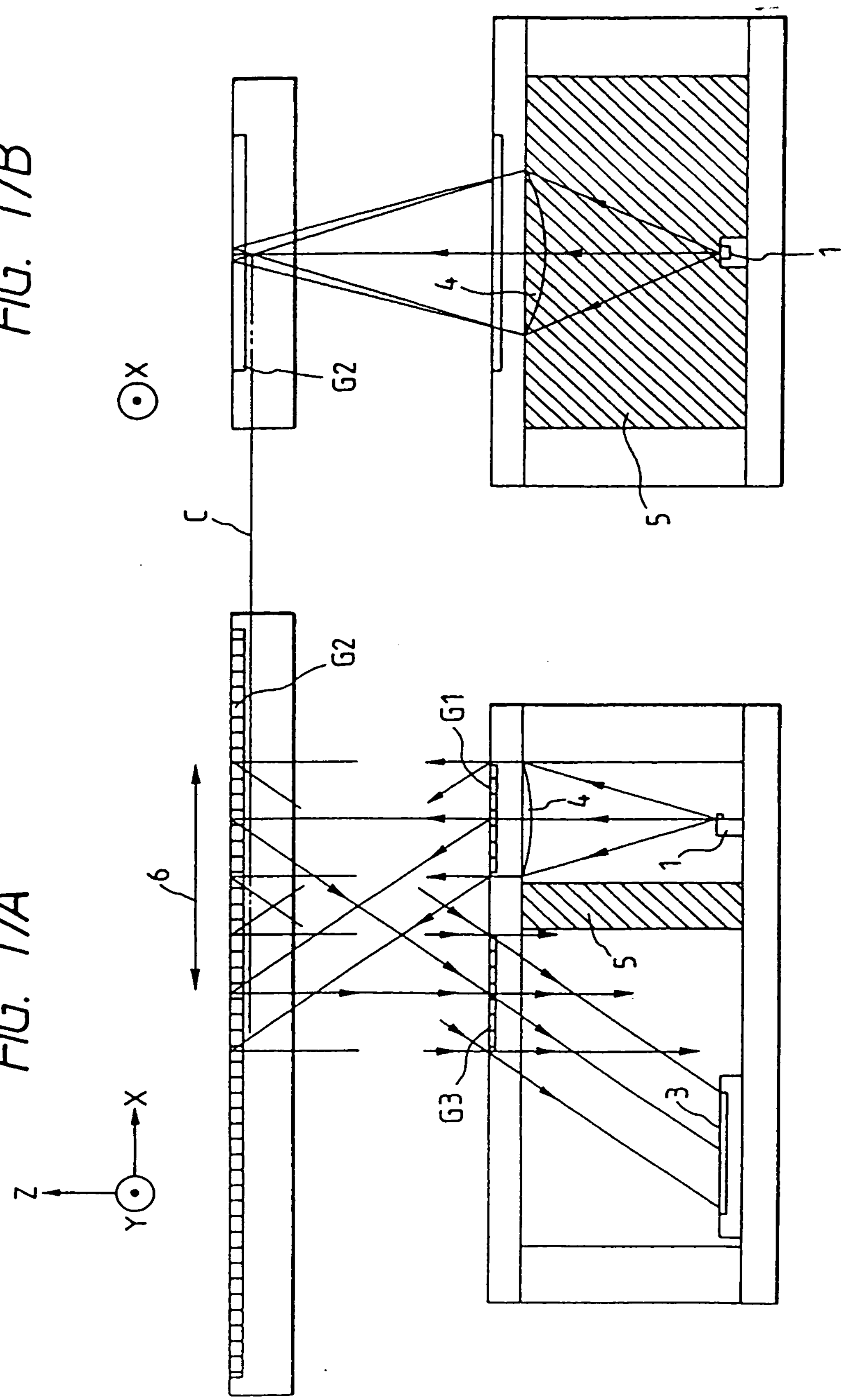


FIG. 16A

FIG. 16B

FIG. 17B

FIG. 17A



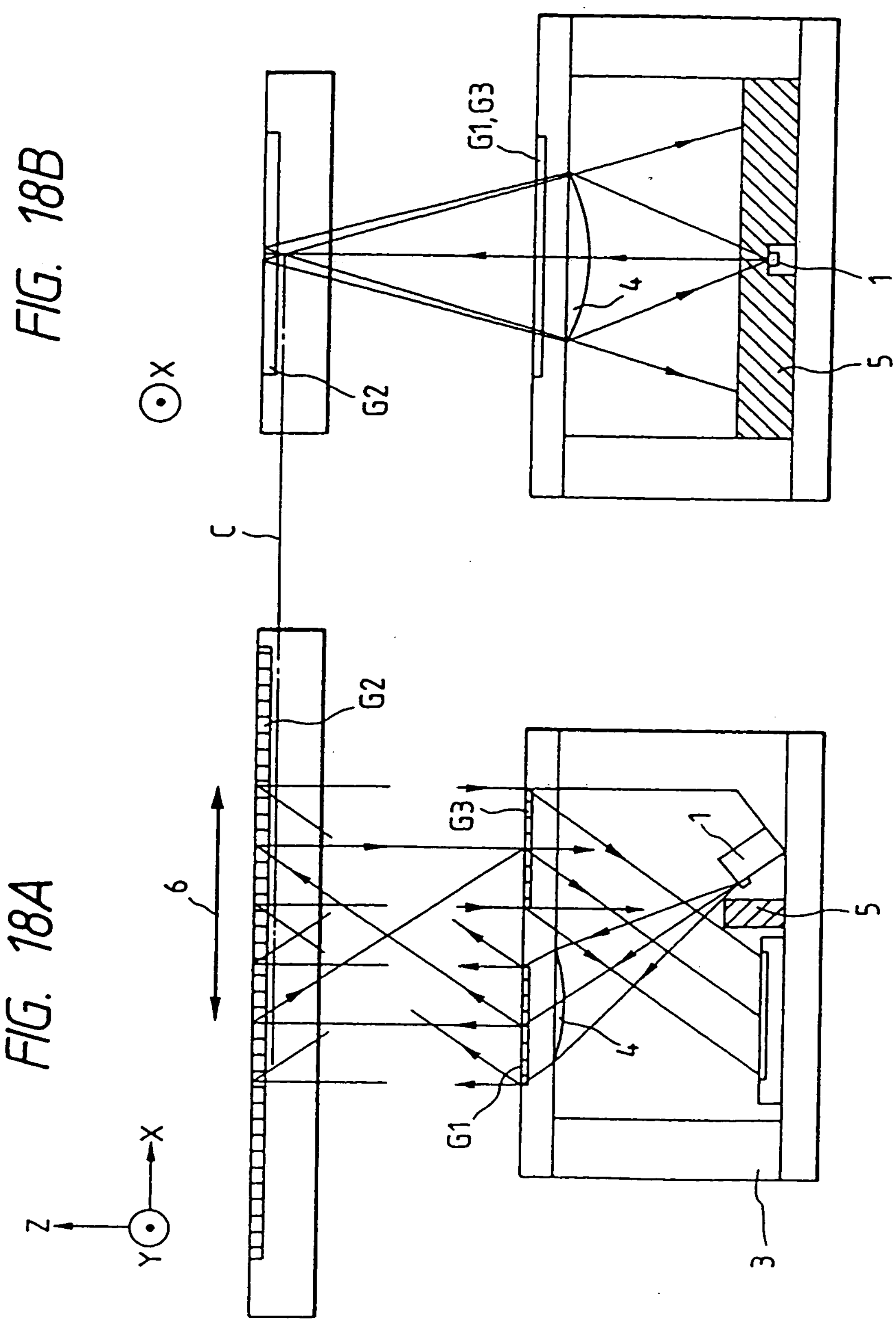


FIG. 18B

FIG. 18A

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 95 10 3588

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	EP-A-0 548 848 (CANON KK) 30 June 1993 * abstract; figures 8A-C 9 * * page 7, line 11 - line 30 * ---	1-3	G01D5/26 G01D5/38
X	DE-A-25 11 350 (NAT RESEARCH DEV CORP LONDON) 9 October 1975 * page 2, last paragraph - page 3, paragraph 1 * * page 7, paragraph 2 - last paragraph * * page 9, paragraph 2; figure 3 * ---	1-3	
X	WERKSTATT UND BETRIEB, vol. 124, no. 2, 1 February 1991 pages 111-113, XP 000320776 SESSELMANN T 'MASSSTAEBE FUER INTERFERENZIELLES ABTASTEN ERMOEGLICHEN NANOMETER-MESSSCHRITTE' * page 113, left column, paragraph 1; figure 7 * ---	1,2	
X	US-A-4 436 424 (BUNKENBURG JOACHIM) 13 March 1984 * column 2, line 15 - line 40; figure 1 * ---	1,10	TECHNICAL FIELDS SEARCHED (Int.Cl.6) G01D
X	DE-A-41 32 941 (HEIDENHAIN GMBH DR JOHANNES) 8 April 1993 * column 2, line 60 - column 3, line 43 * * column 3, line 62 - column 4, line 4; figure 1 * ---	1,2	
A	DE-A-39 05 838 (OKUMA MACHINERY WORKS LTD) 31 August 1989 * figures 2,8,10 * -----	1,2,4-8	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
BERLIN	19 June 1995	Hylla, W

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)